

Chapter

THE ROLE OF UNSTABLE SHOE CONSTRUCTIONS FOR THE IMPROVEMENT OF POSTURAL CONTROL

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ABSTRACT

Postural control has been defined as the control of the body's position in space for the purposes of balance and orientation. Given the mechanical instability of the human body system, the neural process involved in stability organization and body orientation in space is necessary almost all motor actions. To manage movement variability, the postural control system presents a high adaptability in response to changing task and environment demands. The main sensory systems contribute to the development of an internal representation of body posture that is continuously updated based on multisensory feedback and is used to forward commands to control body position in space. For example, understanding the importance of proprioceptive information, and how ankle muscles can influence changes of support and stability that could improve postural control is of significant relevance. The purpose of this chapter is to review and discuss the short and long term influence of wearing an unstable shoe construction on postural control. The review provides instinctive knowledge that can be used during rehabilitation to improve motor performance. It also aims to provide a significant insight into areas that have been dedicated to the implementation of preventive measures, such as ergonomics.

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INTRODUCTION

Postural control is an essential function in daily activities, which varies as a result of the task-individual-environment interaction. [1, 2] Indeed, considering that the body centre of mass (CoM) is located at two-thirds of body height above the ground, the human body is an inherently unstable system that provides a particularly challenging balance task to the central nervous system (CNS). [3] In turn, the CNS has to manage the redundancy of degrees of freedom resulting from the large number of muscles and joints involved to create flexible synergies according to task specificities. [4-9] The neural process involved in postural control is necessary for all dynamic motor actions. [10] In fact, most voluntary movement induces a postural perturbation because of dynamic, inter-segmental forces, and also shifts of the CoM. Therefore, voluntary movements may be considered self-inflicted postural perturbations that may be predicted, to a certain degree, by the CNS, which adjusts the activity of postural muscles both prior to the actual perturbation and in response to it. [11]

Studies on balance and posture during quiet or perturbed standing have identified the dominance of ankle muscles in the anteroposterior direction (Figure 1) and hip abductor/adductor muscles in the mediolateral direction. [3, 12-15] During quiet standing, postural sway results from a combination of inherent fluctuations in the musculoskeletal system, cardiac and respiratory variations, and neural activity. However, it has also been suggested that postural sway serves as an exploratory behavior for the stimulation of somatosensory and vestibular pathways to provide sensory information for increased postural control. [16, 17] By reconciling these two points of view, it is likely that sway characteristics result from an interaction between physiological states, the environment, and the implicit and explicit goals of the current task. [1, 18]

Under normal conditions during standing on a rigid floor, the postural control system elaborates the reference position using information about the relative positions of body segments, muscular torques and interaction with the base of support, taking into account the energy cost of standing and demands for stability and orientation. [19-21] Body alignment can minimise the effect of gravitational forces that tend to pull-off the CoM from the base of support, and muscle tone, i.e., intrinsic stiffness of the muscles, background muscle tone and postural tone, keeps the body from collapsing due to gravity. [1] When postural conditions change, the CNS must identify and selectively focus the most reliable sensory inputs to provide optimal control. As a result of this weighting of afferent input, muscle forces can be produced to control the CoM efficiently to maintain a good equilibrium. [22] Much of the research has focused in quantifying the human response to balance system perturbation in a different number of ways, such as displacement of support surface, predictable and unpredictable external perturbations and internal perturbations. Several factors have been shown to influence postural control responses, but mainly at an immediate level. Taking into account the high adaptability of the CNS [23] in response to changing task and environment demands, [1] it is important to understand the long-term influence of these changes of afferent information that could be beneficial to postural control. Given the importance of the ankle

joint in upright postural control, [24] the influence of an unstable support base in postural control is of significant relevance.

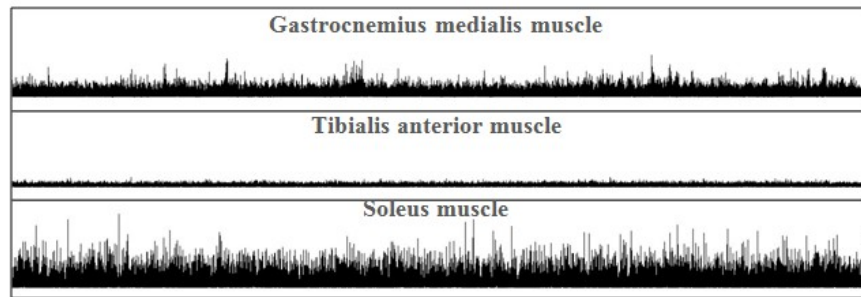


Figure 1. Muscle activity of ankle plantarflexors (soleus and gastrocnemius medialis muscles) and tibial anterior muscle during 60s of upright standing.

Neuromuscular Changes When Standing on an Unstable Support Base

When standing on an unstable support base the new postural requirements lead to postural control reorganisation through increased central drive [25, 26] associated with augmented gamma motoneuron activity leading to higher sensitivity of the muscle spindles [27] and higher muscle co-contraction. [28] However, anticipatory postural adjustments (APA) have been shown to decrease not only in very stable conditions, [29] but also in very unstable conditions. [30] Since the need for stabilising posture is diminished in stable conditions, the requirement for APA is also reduced. [29] Also, APA could themselves be a potential source of perturbation in case of unstable posture, and as such they are also reduced not to additionally destabilise posture. [30] Hence, it seems that the permanence in an unstable support base could, up to a certain level of instability, improve postural control.

Unstable Shoe Construction and Postural Control

Short-Term Postural Control Reorganisation in Response to an Unstable Shoe Construction

During quiet stance on a flat, stable platform individuals sway slightly, and the body oscillates around the ankle-joint axis like an inverted pendulum. [31] When standing on a see-saw (Figure 2), humans project the CoM onto the see-saw's point of contact with the floor. [32]

There is an increased postural sway when wearing rocking shoes, [33] Table 1, expressed by changes in most of the representative CoP displacement parameters, [34] reflecting a situation of high postural demand, which associated to a higher active control at the ankle level [33, 35] would lead to an increased proprioceptive acuity provided by ankle muscles [36] as a result of a higher fusimotor drive. [27, 37, 38] This aspect is supported by recent studies that demonstrated a decrease of onset timing of ankle plantar flexors in response to an external forward perturbation under the condition of higher support instability. [39, 40] The relation between an increase of proprioceptive acuity and the higher fusimotor drive of ankle

plantarflexors (gastrocnemius and soleus) during standing in an unstable support base is acceptable as length signals coming from the less adaptable spindles secondaries provide the CNS with an appropriate input for detecting low-frequency displacements occurring mainly about the ankle [21] and for assisting ankle muscle reflex responses. [41] This interpretation is valid if we consider the studies arguing that ankle plantarflexors are the main responsible for proprioceptive information signaling changes in body position. [42] Recently, based on the fact that during quiet standing reciprocal inhibition could be more important than autogenic stretch reflex, importance has been given to the role of un-modulated muscles crossing the joint in parallel with the active agonist. [43] Under this perspective, the use of unstable shoe construction (Figure 2), not affecting tibialis anterior muscle activity, [35, 39] would be also associated with maintenance of acuity of proprioceptive information provided by the un-modulated muscles, since no differences were observed in antagonist muscles activity in response to the unstable support base condition. In summary, it can be suggested that the higher performance of the postural system when using unstable shoes is associated with increased proprioceptive acuity related to higher motor drive of ankle plantarflexors spindles and to a maintenance of motor drive over muscle spindles of the antagonist.

Table 1. Representation of the variation of CoP displacement parameters obtained during standing with an unstable shoe construction in relation to a stable condition

Unstable shoe condition vs stable condition			
CoP displacement	CoP root mean square	CoP mean velocity	CoP area
↑	↑	↑	↑



Figure 2. Illustration of a kind of unstable shoe construction and a schematic representation of the see-saw adopted in various studies to induce an unstable support base.

Studies about postural control when standing on a see-saw have devaluated the role of the information provided by muscle spindles, arguing that the higher changes in orientation provided by this kind of support surfaces makes it difficult to use proprioceptive information about the relative positions of successive links of the kinematic chain for the reconstruction of a body's position internal representation. [32, 44] As a consequence, the authors gave more importance to the information provided by the Golgi organ tendon. [32] However, it should be noted that the format of the unstable shoes commercialized is different from the see-saw used in previous studies (Figure 2), leading to lower levels of changes in segment orientation at the ankle joint, justifying the maintenance of the role of muscle spindles in this condition.

The influence of the information provided by cutaneous afferents of the feet should be also questioned, considering its importance in standing postural control. [45, 46] However, to date, there is no evidence supporting this possibility.

In association with the previous paragraph, standing in an unstable support base is associated with increased reciprocal activation at the leg, thigh segments and muscle group levels, and lower co-activation levels. [39] Reciprocal activation of the agonist-antagonist set is present when the subject is uncertain of the task to be performed, when a quick compensatory force contraction is perceived to be required, [47] and in joints involving joint movement. [48] Studies using see-saws and continuous rotating platforms have indicated higher joint movement associated with the need of making see-saw rotation to place the support under the CoM. [32, 44] However, because the degree of perturbation induced by commercial unstable shoes is lower than that applied in the studies mentioned, it would be expected higher co-activation levels in the unstable support base condition, as co-activation has been described as the most robust strategy to counteract perturbations [49-52] by increasing joint stiffness. [53-57] However, the results obtained in recent studies [33, 39] indicate that wearing unstable shoes leads the postural control system to rely more on reflex feedback more than on stiffness increase to compensate for the decrease of stability, which has been demonstrated to be more efficient and accurate, but also more challenging for the postural control system. [58-64] This synergy pattern selection in association with the changes occurred in the magnitude of ankle muscles activity only [35] indicates that this kind of unstable shoe leads to instability levels that are perfectly managed by the CNS as a low perturbation. [65, 66] In fact, the postural performance is not modified when exposed to an external perturbation. [39, 40]

The higher demand over postural control in an unstable support base led to changes in the neuromusculoskeletal system, mainly at the ankle joint, leading also to positive effects over the venous return. [35] This could be related to the increased activity of the gastrocnemius muscle, to the kind of contraction imposed, as well as to the increased reciprocal activation.

Long-Term Postural Control Reorganisation in Response to an Unstable Shoe Construction

After prolonged standing in an unstable support base, the individual muscle activity, as well as the relation between agonist and antagonist, are close to the necessary for a stable support base condition. [33, 35, 40] However, exceptions were observed at the thigh level as reciprocal activation remained higher in the unstable condition [33, 40] associated to an increased biceps femoris activity in automatic and voluntary compensatory response and decreased gastrocnemius medialis activity. [40] These findings suggest a transfer of postural control synergy for the thigh which has been reported as more beneficial to optimise postural stability. [13, 19, 67-69] In fact, CoP parameters indicate higher performance by the postural control system in compensatory responses after prolonged wearing of unstable shoes, [40] and the relation between CoP and CoM [33] indicates a higher performance and efficiency [70, 71] of the supraspinal process, as well as of the action of spinal reflexes and/or of the intrinsic mechanical properties of muscles and joints. [72] Bearing in mind the important role of the information provided by group II fibers in postural control during standing, [41, 73-77] it can be hypothesised, based on the findings presented by Sousa et al., [40] that decreased gastrocnemius activity after prolonged wearing of unstable shoes could also be related to a possible decrease of medium latency responses. This hypothesis is based on the evidence that

medium latency responses mediated group II afferences are more influenced by the postural set and are the only that have a stabilising effect during perturbation of stance. [78, 79] The maintenance of decreased values of ankle muscle latency, even after prolonged unstable shoe wearing, [40] can be related to a remaining instability effect expressed by the higher activity of total agonist activity and higher values of CoP displacement in the unstable support base condition. [33]

From the findings and observations presented in this chapter, [33, 40] it is evident that prolonged wearing of unstable shoes leads to improved postural performance and efficiency. Also, even after adaptation by the postural control system, the venous return is higher in the unstable support base condition than in the control condition. [35] The results obtained by Sousa et al. [40] suggest that the main factor responsible for increased venous return is related to the kind of muscle contraction of plantarflexors, since dynamic muscle contractions favour venous circulation. This conjecture is sustained by higher CoP displacement values observed after prolonged wearing of unstable shoe [33] and by studies on see-saws. [32, 44]

The impact of postural control strategies on venous return is of significant relevance in healthy subjects that are in risk of developing venous insufficiency, but also in subjects with venous insufficiency. Chronic venous insufficiency explains those manifestations of venous disease resulting from ambulatory venous hypertension, which is associated with failure of the lower extremity muscle pumps due to outflow obstruction, musculo-fascial weakness, loss of joint motion or valvular failure. [80-83] Although the effect of an unstable support base has been explored only in healthy subjects, beneficial results would be expected in subjects with venous insufficiency, as balance training has been demonstrated to promote improved postural control performance both in healthy subjects [84-90] and in subjects with ankle muscles impairment. [87, 91] This is of significant relevance since it has been demonstrated that calf muscle strengthening exercises restore the pumping ability of the calf muscle and improve the haemodynamic performance in limbs with active ulceration subsequent to severe venous valvular and calf muscle pump impairment. [92-94]

CONCLUSION

This review chapter has discussed the role of instability imposed by rocking (unstable) shoes and how it may lead to positive effects over the postural control system. This effect appears to be related to higher acuity muscle spindles at the immediate level and after a long-term exposure. The changes occurred in terms of ankle muscle activity in response to an unstable support base favour venous circulation even after training adaptation by the neuromuscular system. Considering the review presented in this chapter, the use of unstable shoe constructions should be encouraged in rehabilitation as a strategy to improve postural control performance.

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